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Climate Change Narratives

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Reconstructions of Earth's past are much more than benchmarks for climate models. They also help us comprehend risk by providing concrete narratives for diverse climates.

In central Spain, outcropping on dusty hillsides overlooking apparently endless miles of gnarled olive trees, is the Esplugafreda Formation – 250 m of rusty-coloured paleosols interspersed with calcareous deposits, ancient channels, part of an >55 million year old braided river system. What is particularly striking about these rocks is that atop them sits the Claret Conglomerate, a unit not of silt, sand and ancient soil but of pebbles, fist-sized stones and even boulders, part of the same river system but deposited under conditions with far more energy. It represents a relatively transient moment in Earth history of remarkably intense rainfall events. And it was likely caused by ancient global warming.

Palaeoclimatologists, those who study past climate using a combination of fossils, chemical proxies and reconfigured climate models, have long argued that our work can help us better anticipate the future, anthropogenically-influenced world. This is especially true as we pass 400 ppm of carbon dioxide in the atmosphere, a level that our planet has likely not experienced for 3 million years[1], and continue towards 800 ppm, a level likely not experienced for ~30 million years[2]. These ancient climates allow us to test the climate models on which future projections are based. They allow us to explore the impacts of climate change on ecosystems and complex, interlinked Earth system processes. And they allow us to identify important processes that have perhaps not yet been incorporated into climate models.

Earth history, however, has an even deeper role to play in the modern conversation and public understanding of climate change – it helps us comprehend and navigate the contextualised and multifaceted uncertainty associated with climate change forecasting. As President Donald Trump withdraws the United States from the Paris Agreement, adding another degree of uncertainty to our future, new gateways to climate change literacy and engagement are needed more than ever.

There is much that we know, much that is known within certain probability distributions, much that is anticipated but difficult to forecast due to system complexity and much that remains unknown. This creates a hierarchy of uncertainty and risk in which poorly constrained climate change impacts can be conflated with and cause confusion about the more certain ones. We need to communicate the opposite: what is well understood in climate science contextualises the more uncertain aspects.

Some facts are now certain or near certain[3]: atmospheric carbon dioxide and methane levels are increasing, both due to human activity; these increases have caused warming over the past half century and will cause further warming in the future. Warming will cause sea level rise via thermal expansion and ice sheet melting, and storms likely will be associated with greater precipitation and more flooding as the moisture holding capacity of the atmosphere increases. These are the tier one facts of climate change science. But there is uncertainty with those estimates. How *much* warmer? How *much* more rain? How *fast* will ice sheets melt? And uncertainty increases as our attention becomes more regionally focussed and our questions more detailed – especially with respect to ecological and societal impacts[4]. *Where* will rainfall increase or decrease? How does that affect your particular city or the farmland from where your food comes? How does a combination of more carbon dioxide, warmer air, and changes in rainfall and soil moisture affect forests and jungles? How do those factors, combined with ocean acidification, affect coral reefs, marine ecosystems, and global fisheries?

We are making great strides in reducing these uncertainties, whether it be via more sophisticated Earth system models, greater computational capacity or better understanding of underlying processes. But the uncertainty remains profound, especially and unfortunately for those aspects of climate disruption – from extreme weather to food production – that most concern policy makers, industry and the public. This disconnect between our robust understanding of climate change fundamentals and its specific and localised impacts is clear to anyone who works with decision makers; it was certainly clear to me when Bristol developed its 50-year Resilience Strategy[5] (with the support of the 100 Resilient Cities initiative of the Rockefeller Foundation). The continuum of understanding, from certainty to deep uncertainty and with which scientists are relatively comfortable, can cause profound confusion. If we cannot even understand how rainfall in the SW of England will change, do we understand anything?

Of course we do. What we do understand sharpens our concern about the risks that we do not. But conveying that and providing meaningful guidance in that context is challenging.

The past informs the future

Palaeoclimate, therefore, provides a vital and powerful component to the cultural adoption of climate change understanding. Rather than asking decision makers to understand a mathematical continuum of increasing uncertainty incorporated into Earth system models, from radiative forcing to cloud nucleation to biogeochemical feedbacks, and the associated emergent complexity, palaeoclimate research can present the same information as an experiential suite of observations and associated narratives.

Primarily, Earth history shows us that climate can change. We live during a particularly protracted period of climate stability, the Holocene, that has allowed civilisation to thrive. Even on those relatively modest timescales, however, the concept of climate change has become embedded in our mythology, religion, culture and art, from biblical floods to Dutch paintings of frozen canals. And geological endeavour has ensured that we are well aware of the far more dramatic changes of Earth history. Glacial striations in the American Midwest, coal deposits buried beneath deserts, vast salt deposits in the Mediterranean Sea and crocodile fossils in the Eocene Arctic have been incorporated into our cultural imagination, manifested as pop culture images of brachiosaurs trundling through hot swamps or herds of woolly mammoths foraging in the shadows of ice sheets.

But Earth's climate change does not change randomly. It has changed and will continue to do so due to processes that are increasingly well understood. Crucially, our proxies for past carbon dioxide, despite their uncertainties and eccentricities, nearly universally show that when concentrations of carbon dioxide in the atmosphere were high, our planet was hot and in a manner consistent with climate models[1,2] (although models appear to underestimate polar warming[6]). The Earth does warm and, to the first order, we understand why.

The Claret Conglomerate was deposited during such a warming event, the Paleocene Eocene Thermal Maximum (PETM), about 56 million years ago[7]. The evidence for an increase in carbon dioxide concentrations, a pronounced shift in the carbon isotopic composition of the atmosphere indicating an injection of 'light' CO_2, is among the strongest in all of Earth history[8]. Also robust is the evidence for pronounced global warming of 5 to 8°C, responses derived from numerous locations and diverse organic and inorganic proxies[9]. The carbon dioxide increase at the PETM caused the oceans to become more acidic – a direct chemical consequence of adding more carbonic acid to the oceans, evidenced by the absence of calcium carbonate in deep sea sediments and biotic turnover among deep-sea calcifying organisms[10]. The Paleocene and Eocene were also characterised by a lack of extensive continental ice and much higher sea level – evidence that at elevated CO_2 levels, Greenland and Antarctic ice sheets will eventually melt, raising sea level by 70m or more, far more than the ~1 m predicted for the end of this century.

There are a multitude of similar stories from Earth history.

Crucially, the relative simplicity of those observations provides the context for exploring more complex aspects of climate change in response to global warming. The PETM Claret Conglomerate is evidence for more extreme rainfall, but is it evidence for a wetter climate in Spain or perhaps a drier climate with more intense and episodic events?[7] The same question can be asked of the change in clay assemblages deposited in marine sediments during the PETM or the widespread increase in sedimentation rates in marginal marine settings[11]. We can apply more complex proxies, such as the hydrogen isotopic ratio of leaf waxes which suggest an increase in moisture transport to the poles[12]. Collectively, these data indicate that global warming caused a significant reorganisation of the global hydrological cycle with significant meteorological change in many locations. That is a simple and powerful observation, regardless of the uncertainty associated with the details (although those details remain important).

The PETM also allows us to explore the potential consequences for terrestrial ecosystems. Floristic changes were widespread[13], accompanied by soil faunal[14] and mammalian dwarfism[15]. Soils, especially in continental interiors, became more barren perhaps due to increased erosion or perhaps due to increased oxidation of organic matter under hotter and wetter conditions[16]. These changes on land appear to have profoundly affected the oceans. Intense storm events stripped soil from the land, delivering nutrients to the coastal seas, burying some coastal benthic ecosystems while providing nutrients for planktic ones. Degradation of the organic matter produced by algal blooms stripped oxygen from some marginal seas, including parts of what were to become the Gulf of Mexico, the Arctic Ocean and the Mediterranean Sea[17]. Life, both on the land and in the sea, was profoundly transformed for tens of thousands of years.

The past does not necessarily predict risks associated with climate change but it assures us they are real.

Comprehending and navigating uncertainty

It is unclear if these deep time paleoclimate observations have or will directly improve forecasts for 21st century global warming impacts. They have done so indirectly, by signposting gaps in our understanding and revealing new directions of research. And certainly, they help constrain natural climate variability and confirm mechanisms underpinning climatic and biogeochemical responses. Nonetheless, it is Earth system models on which we rely and will continue to rely for managing our uncertain future.

Regardless of how Earth history improves our climate forecasts, however, it serves two other essential roles related to how we *engage* with those forecasts. First, it confirms that the risks expressed in such models – from heat waves, sea level rise, flooding, drought and soil loss to enhanced stress on already stretched agricultural and natural systems – do exist. Natural global warming caused such things to happen in the past; anthropogenic global warming could cause them to happen again. By extension, risks that remain poorly understood should be a source of greater rather than lesser concern – we know enough to worry but, in some cases, not enough to plan. Consequently, such risks should motivate more rapid and bolder climate change mitigation rather than being an excuse to prevaricate[18].

Second, the inherent uncertainty associated with some climate change consequences requires a more dynamic and evolvable strategy, represented by the recent trend to discard adaptation narratives for resilience and social justice ones. Some consequences of climate change, such as how it will impact flood risk or food security, remain associated with profound uncertainty. Other consequences, such as increased erosion and sedimentological change, are evident in the geological record but barely register in Earth system models used to explore the future. To address these challenges, whether for a 1.5^{o}C warmer world or more, our adaptation and resilience thinking must continue to evolve. It is difficult to pre-emptively adapt to crises for which our predictive capacity is limited. Instead, our decisions today should anticipate an uncertain future, enabling or creating the flexible political, financial and physical structures that will empower local communities and future generations[5].

This is a challenge and an opportunity. Past climate research helps us understand the future but it also subverts conventional ideas of resilience by showing the complexity, variety and in some cases unpredictability of global warming consequences. In doing so, it could provoke new ways of engaging with our future, liberate creative and inclusive thinking and inspire new types of solutions.

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